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Engine Health Management for Aircraft Propulsion Systems

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Health Management Definitions

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Data: Basic Measured Characteristics
Information (Features): Useable (Actionable) Knowledge Derived from Data

Diagnostics: Current Condition of Component/System to Perform Function via *Sensing*
Prognostics: Future Ability of Component/System to Perform Function via *Reasoning*

Degradation: *Slow* Loss of Health Over Time
Fault: *Rapid/Abrupt* Loss of Health Due To An Event
Failure: Termination of Degradation/Fault Condition

Detection: Basic Identification of Occurrence Symptoms of Degradation/Fault
Isolation: Resolving of Health Degradation/Fault to Specific Component(s)

Monitoring: Observation/Measurement of Component/System Health
Management: Proactive Capability to Make Decisions About Component/System Health

Health Management Definitions

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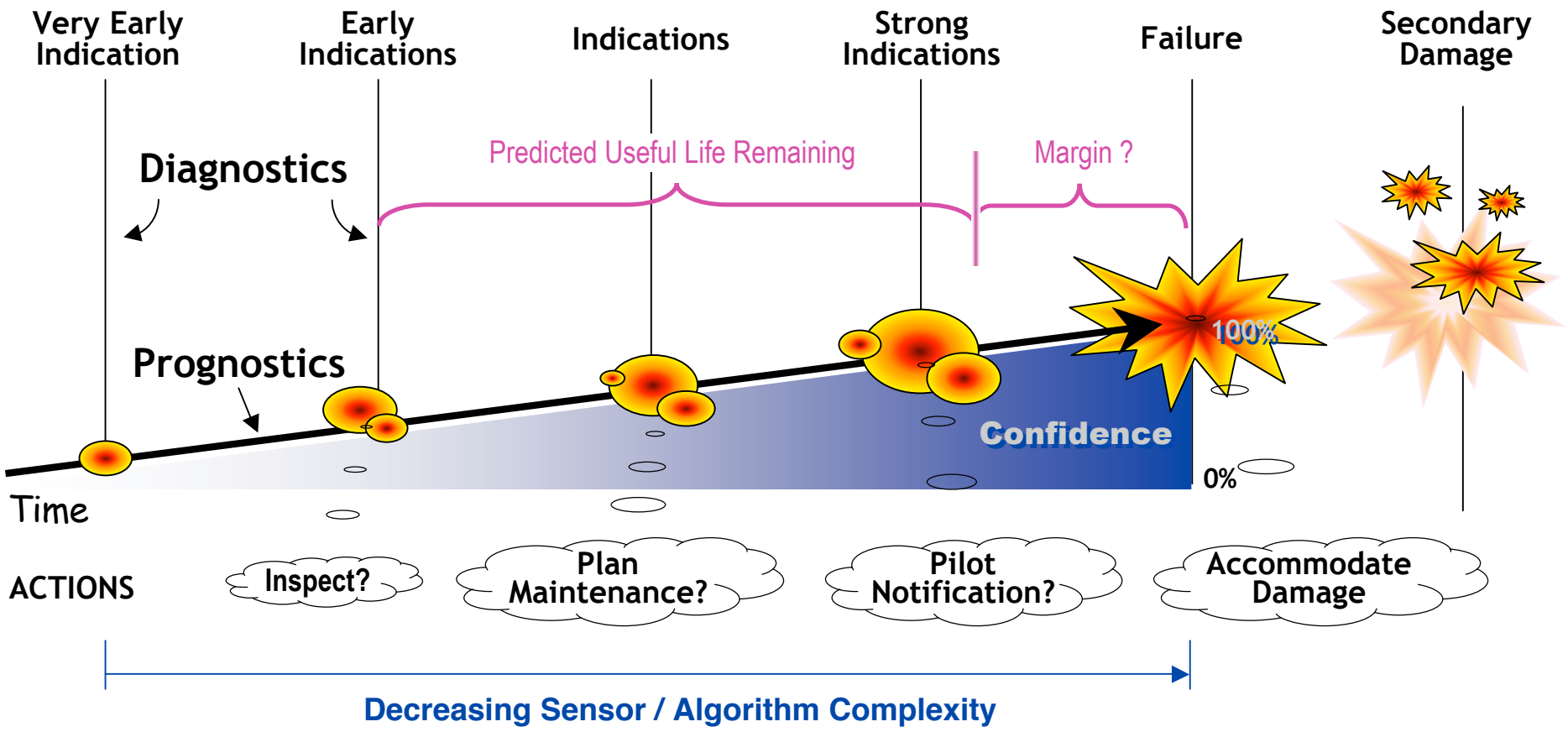
Failure Progression Timeline



Drivers for Health Management

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Many Different Perspectives

Line Maintainer Perspective

- Wiring Diagnostics
- Event Troubleshooting
- Borescope Inspection
- Vibration Survey / Trim Balance
- Lubrication System Inspections
- Oil Consumption Monitoring
- Filter Inspections / Troubleshooting
- :

Logistics Manager Perspective

- Maintenance Cost
- Support Personnel
- Unit Level Part Consumption
- Sustaining Support
- Indirect Support / Shop Operations
- :
- :

Fleet Manager Perspective

- Avoid Engine Damaging Events
- Faster Troubleshooting
- Accurately Identify Line Replaceable Units
- Improve Shop Planning
- Limit High Power Troubleshooting Ground Runs
- Smaller Rotating / Spare Engine Inventory

Integrated Health Management

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Putting Together the "Puzzle"

There Is No "One-Size Fits All" Solution

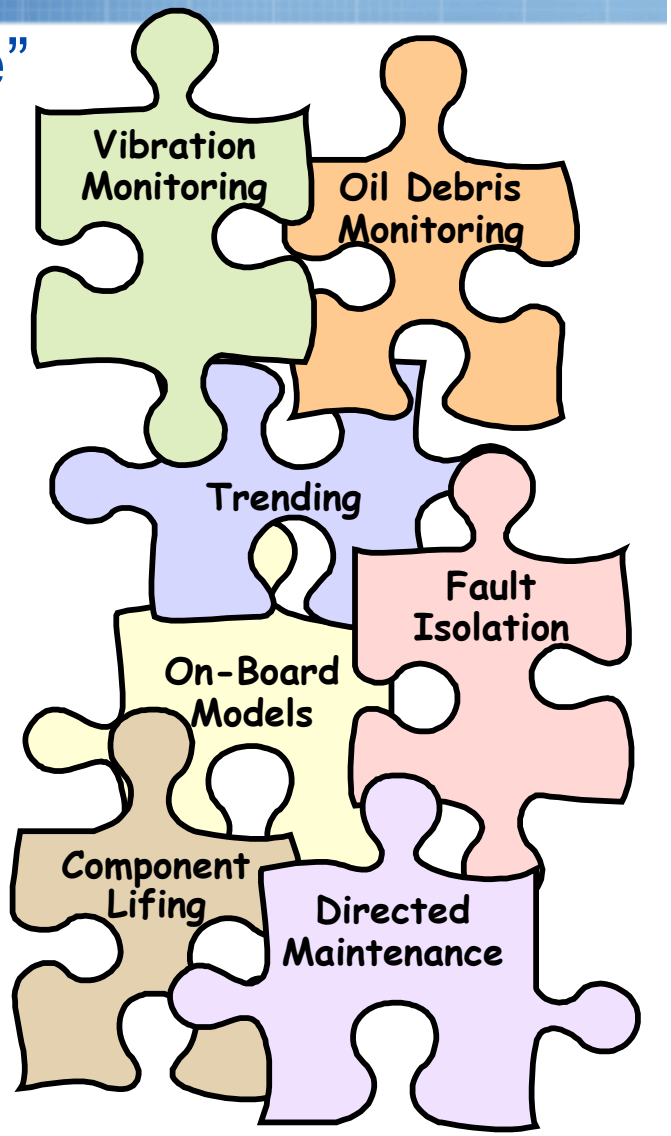
- System Requirements Vary for Different Engines/Aircraft
- Various Customers Will Have Different Needs
- OEM Customer: Fleet Management Plans

Not A Decision Between On-Board vs Off-Board

- Need Both On and Off-Board Capabilities
- Determine "Where Best To Do What" for Each Application

Data Flow Drives Need for Vehicle Integration

- Need Means to Get Data to Maintainer / Fleet Managers
- Unified Vehicle Data Transfer System Offers Benefit



"Pieces of the Puzzle"

Integrated Health Management

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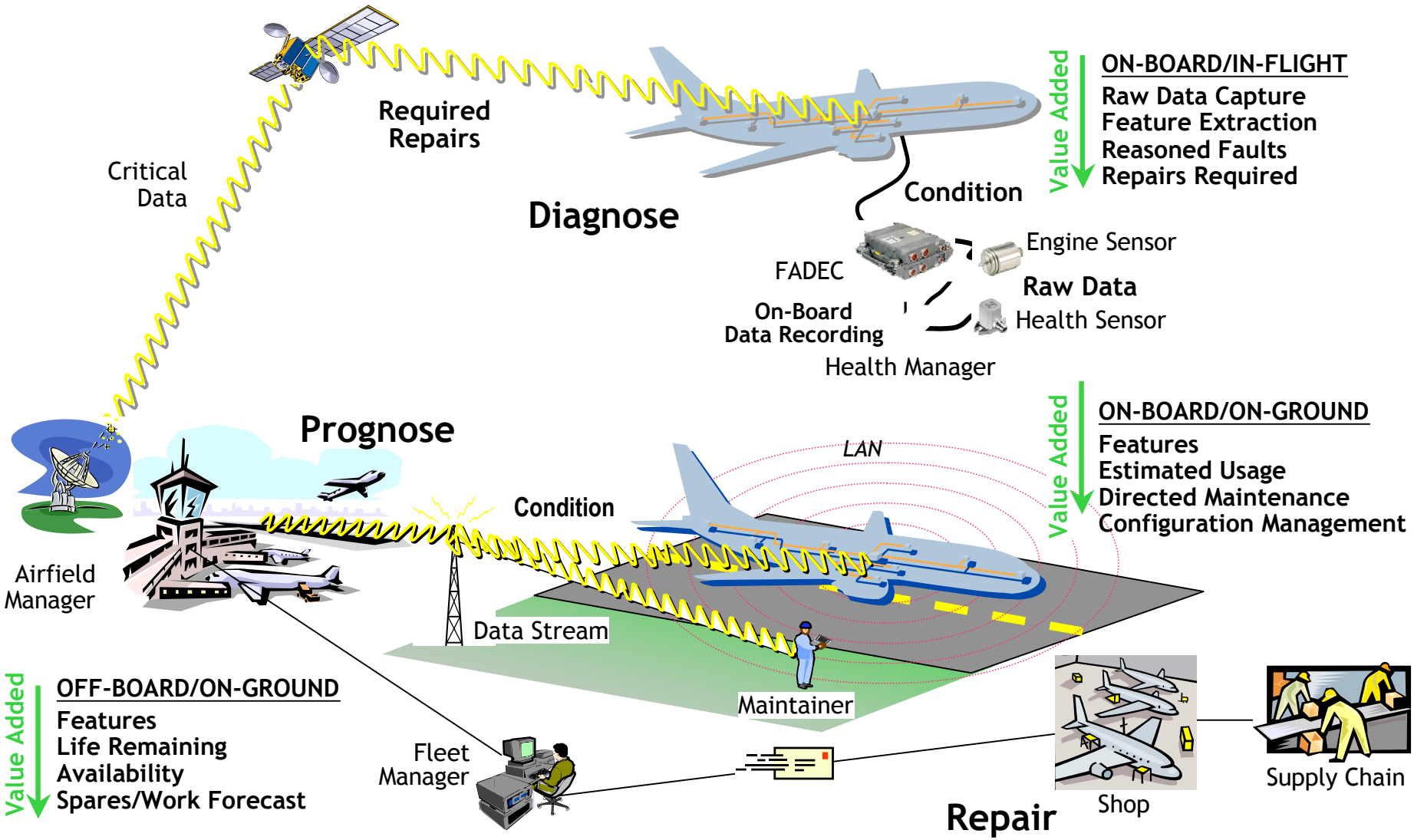
Many Options: Key is Finding Right Mix of On and Off Board Capabilities



Health Management Capabilities

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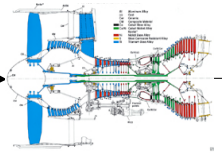
Gaspath Performance Monitoring

Self **T**uning **O**n-board **R**eal-time **M**odel

State Variable Model

Engine inputs,
Wf, Bleed Cmds, etc

Inputs



Simulated Parameters:
Speeds, Pressures,
Temperatures, etc

Estimated
Parameters

Measured
Parameters

\+

−

Measured Parameters:
Speeds, Pressures,
Temperatures, etc

Residual

Residual represents
difference between Model
simulated data and
measured data

Tuners update Model
to account for observed
differences (residuals)

Tuners

Kalman Filter

Kalman Filter Observer

Calculates changes in
Module Performance to
drive residual to zero

Tuners represent changes in Module Performance, i.e. Δ efficiencies and flow parameters indicative of deterioration, component damage and/or **build variations**.

Health Management Capabilities

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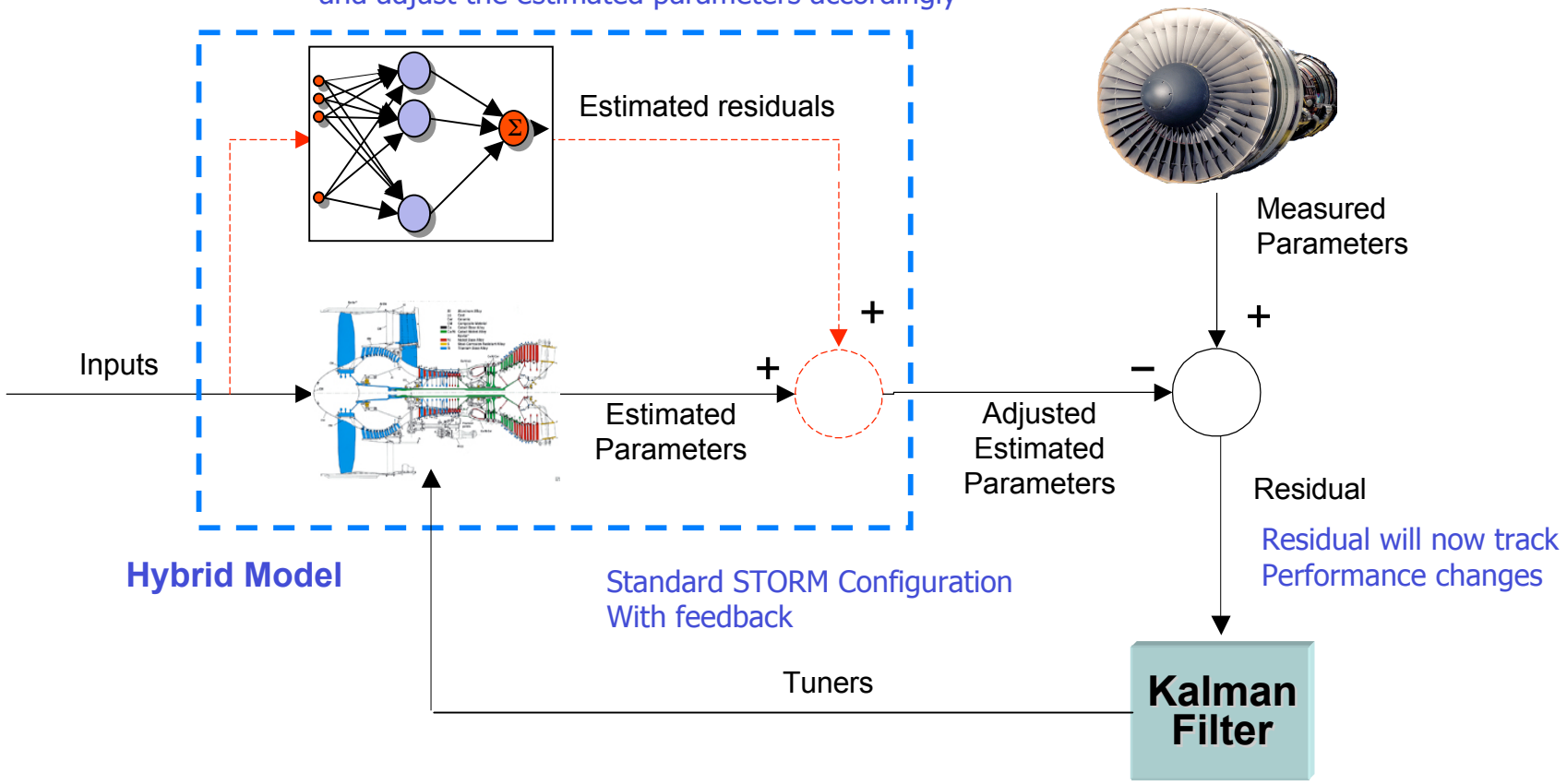
Gaspath Performance Monitoring

enhanced Self Tuning On-board Real-time Model

Trained Artificial Neural Net (ANN) estimates the difference between the Model and the actual Engine and adjust the estimated parameters accordingly



Health Management Capabilities

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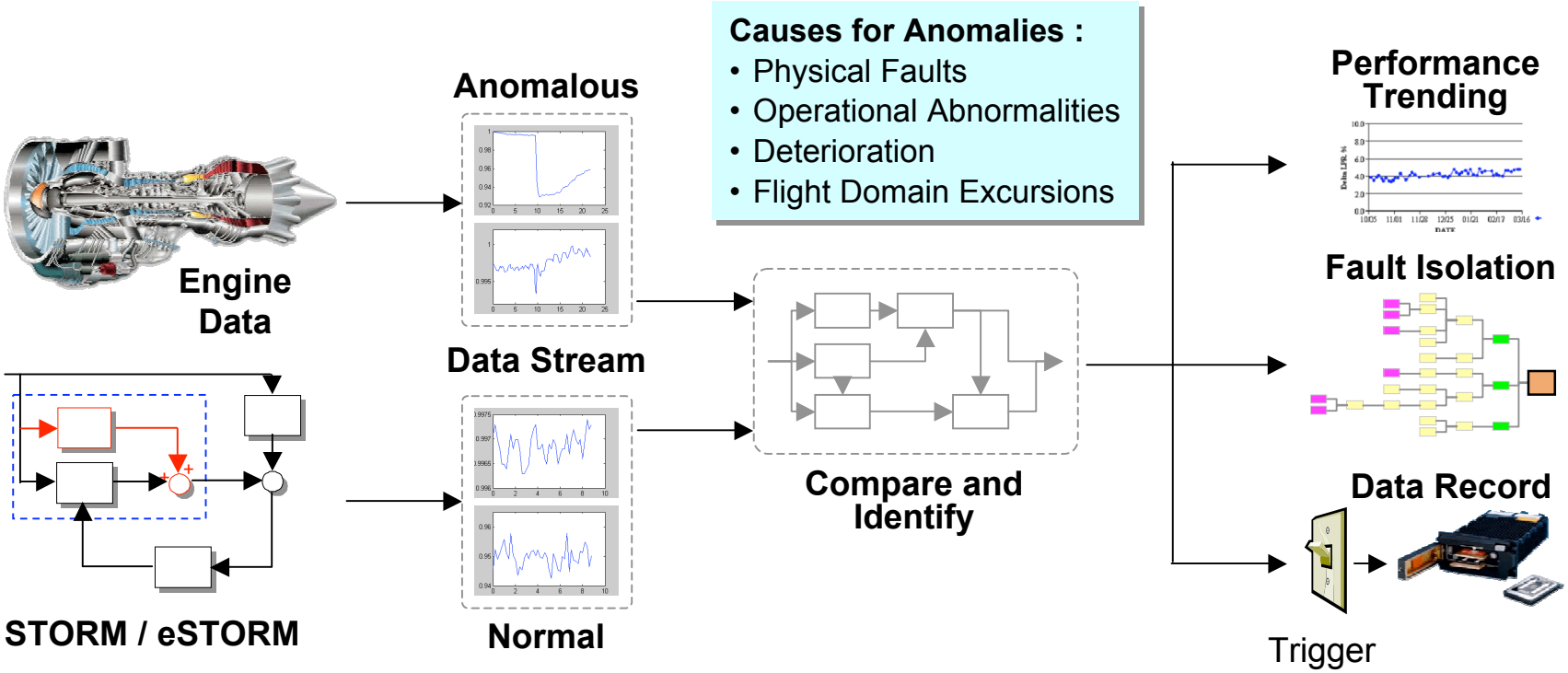
Gaspath Performance Monitoring
Anomaly Detection



Anomaly Detection: Identify Differences from "Normal"

- Provides Trigger to Capture Real-Time Data for Subsequent Off-Board Analysis
- Additional Data to Support Fault Isolation
- Element of Long-Term Performance Deterioration Tracking

Health Management Capabilities

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Gaspath Performance Monitoring – Benefits

Parameter Synthesis for Virtual Sensor

- Analytical Redundancy
- Airflows, Difficult to Measure Temperatures/Pressures, Thrust, etc.
- Sensor Substitution
- More Information from Fewer Sensors

Performance Deterioration Trending (Gas Path Analysis)

- Estimate Performance Shifts (e.g. Flow capacity, Efficiency, etc.)
- Input Errors (Stuck Bleeds, etc.)

Fault Detection

- Isolate In-Range Drifts / Failures

Reliability and Cost Benefits

- Early Warning of Component Degradation
- Dispatch and Cancellation Rate via In-Flight Notification
- Damage Avoidance

Control Adjustments for Deterioration

- Ratings Adjustments for Deterioration

Health Management Capabilities

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Mechanical Systems Monitoring

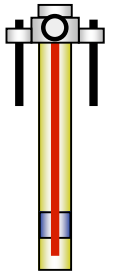
Typical Suite of Sensors

- Oil Temperature
- Fuel Temperature
- Oil Filter Pressure Drop: **Filter Health**
- Fuel Filter Pressure Drop: **Filter Health**
- Oil Pressure
- Oil Quantity: **Oil Consumption**

Oil Debris Monitor

Sensors Available

- **Oil Debris: Size/Rate of Particles in Oil**
- **Oil Condition: Thermal Degradation of Oil Itself**
- **Improved Oil Quantity/Level Sensing**
- **Gearbox Vibration (High Frequency)**



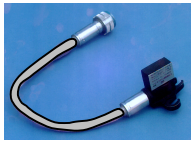
Oil Level & Condition Monitor

Models:

- **Select Fuel and Lube Elements**

Algorithms Available

- **Level and Rate Trending (Similar to Gaspath Analysis)**
- **Real-Time Vibration Analysis**



Vibration Monitoring

Health Management Capabilities

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Structural Monitoring

Typical Suite of Sensors

- Vibration Level (by Aircraft)

Sensors Available

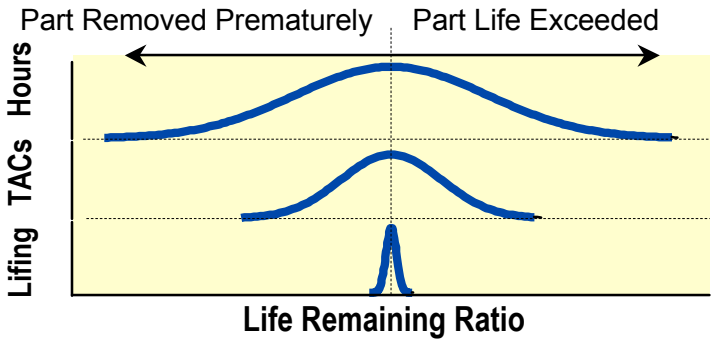
- Case Vibration Monitoring (by Engine)
- FOD/DOD Debris: Particle Monitoring
- Blade: Clearance and Passage Monitoring

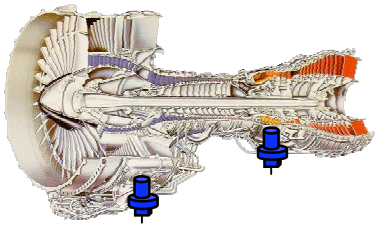
Models:

- Structural Transfer Functions
  - Measurement(s) to Component Condition

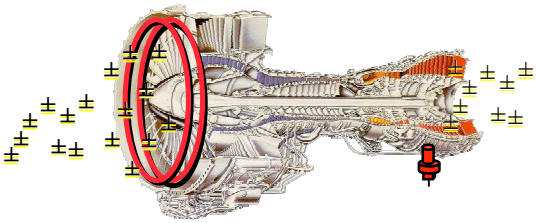
Algorithms Available

- Real-Time Vibration Analysis
- *Component Life Usage / Life Remaining (Below)*

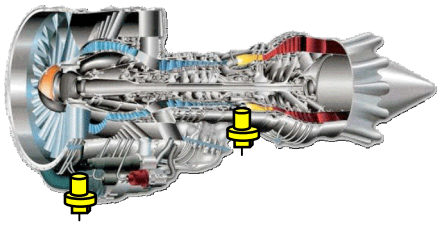




High Frequency Vibration Monitoring



Debris Monitoring



Blade Monitoring

Health Management Capabilities

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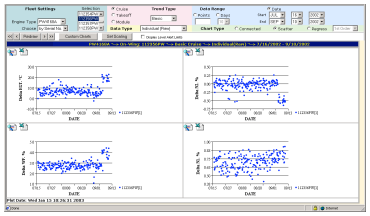
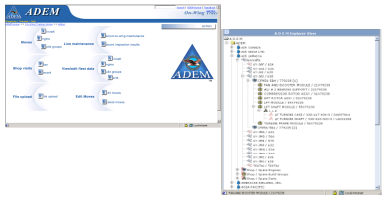
Off-Board: Maintenance Support Tools

Diagnostics and Prognostics → **On-Condition Management** → **Removal and Shop Visit Planning**

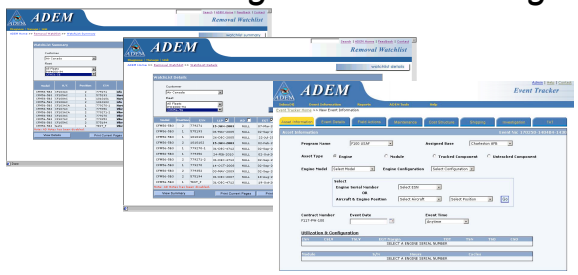
Trending



Configuration and Utilization Tracking

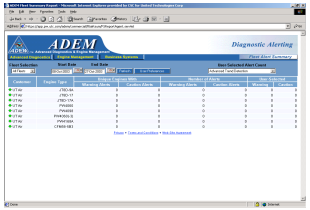


Removal Planning / Event Tracking

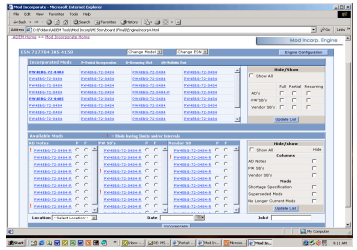


Early Warning Detection

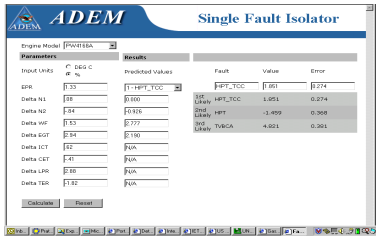
Fleet Alert Summary and Watchlists



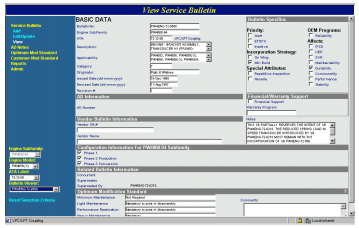
Modification Incorporation



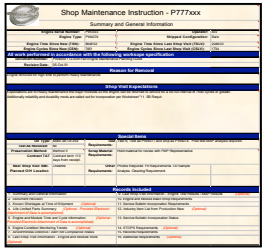
Isolation



Modification Standardization



Shop Maintenance Instructions



Integrated PHM Architecture & Technology Improves Value

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Value

Reduced

Schedule Interruptions
Troubleshooting Time
Maintenance Costs
UERs, D&Cs, IFSDs

Improved

Life Management
Cost of Ownership
Time on Wing
Forecasting

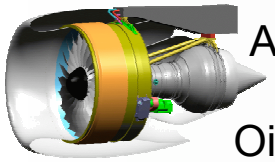
Ground

Fault Forwarding / Directed Maint.
Prognostics, Trending, Alerting & Isolation
Fleet Watchlists
Configuration./Utilization. Tracking
Life Extension
On-Condition Fleet Mgmt
Shop Visit Optimization

Aircraft & Systems

Performance & Trending Data Acquisition
Exceedance Monitoring
Advanced Vibration Monitoring
Nose-To-Tail Fault Forwarding
Data Storage & Communications

Engine



Anomaly Detection
Advanced Vibration
Life Usage
Real-time Models
Oil System Press/Temps/Debris
Oil/Fuel Filter Health
Gas Path Press/Temps